The Impact of Turbulence on Sun-Earth-Connection Physics

If turbulence is present, it cannot be ignored.

Fundamental Question Addressed

How does the turbulence in the solar-terrestrial environment affect Sun-Earth-Connection physics?

Importance of the Question

In fluid dynamics, the presence of turbulence at even a small amplitude alters global flow patterns and can enhance momentum transport diffusion, mixing, and surface drag by many orders of magnitude. Basically, fluids behave differently when they are turbulent. One suspects that the same is true for MHD plasmas. The plasmas of the solar-terrestrial environment are turbulent, and the SEC community risks a grave error if this turbulence is ignored. To optimize our scientific progress, an effort should be made to assess the role that turbulence plays in each process that is investigated under the SEC program.

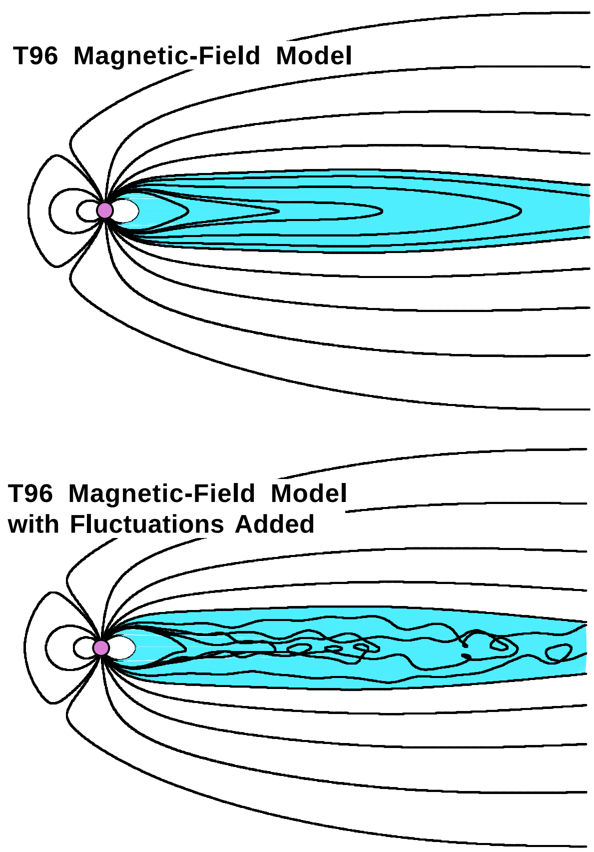

Fig. 1. A conceptualization of the magnetotail obtained by adding magnetic-field fluctuations to the Tsyganenko T96 field model. The properties of the fluctuations match the statistical properties of the plasma-sheet turbulence as measured by ISEE-2.

Science Objectives

The fundamental objective is to answer:

♥ **What are the impacts of turbulence in the solar-terrestrial environment?**

This includes the solar atmosphere, the solar wind, the magnetosheath, the plasma sheet, the plasmasphere, and the ionosphere. For each of these the objectives are to answer the following:

♥ What is the nature of the turbulent fluctuations?
♥ How is the turbulence driven?
♥ How is the turbulence dissipated?
♥ How is the turbulence affected by boundaries?
♥ How does the turbulence affect large-scale flow and dynamics?
♥ What critical processes are affected by the turbulence?

What Needs to Be Done

A coordinated effort involving experiments, data analysis, computer simulations, and theory is needed (1) to gain an understanding about the turbulence that is prevalent in the solar-terrestrial environment and (2) to quantitatively assess the impact of turbulence on SEC physics.

Strategy

A basic strategy for the SEC community is:

- gather the observations needed to build turbulence models
- consider the consequences of that turbulence
- utilize existing data to study turbulence
- discern whether our simulation codes operate with proper Reynolds numbers
- utilize global simulations to discern how turbulence is driven and what affects it has
- design future missions to obtain critical information about turbulence in the environment
- create an interdisciplinary theory program

Technology Requirements

- faster and more-accurate measurements
- advanced computational physics

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The Impact of Turbulence on SEC Physics

☛ Laminar-flow equations do not describe the average of a turbulent flow.

Nearly a century of fluid research has repeatedly shown the lesson that, if getting the right answer matters, turbulence cannot be ignored. So far, that lesson has not been learned by the SEC community. Flow turbulence enhances transport and coupling by orders of magnitude. The presence of even a small amplitude of turbulence can greatly alter the time-averaged flow pattern, so averaging over the turbulent fluctuations is not an option. Laminar-flow equations do not describe the average of a turbulent flow.

Some of the major effects of turbulence (even for small amplitudes) in fluids are:

- enhanced transport of mass and momentum
- enhanced drag on boundaries and obstacles (see Fig. 2)
- mixing and turbulent diffusion
- turbulent heating and enhanced heat flux
- alteration of large-scale flow pattern
- changing of instability thresholds

For plasmas, which are more complicated than ordinary fluids, the effects of turbulence may be even further reaching.

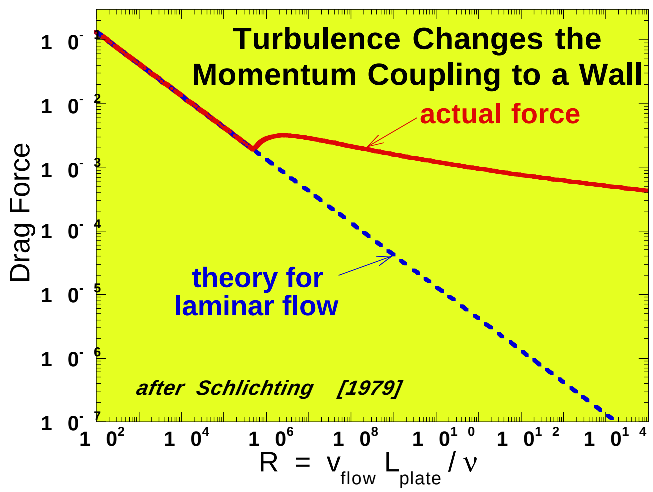

Fig. 2. The drag force on a flat plate (fin) in a flow versus the flow Reynolds number R. At high R the flow near the plate is turbulent.

Turbulence is ubiquitous in the plasma flows of the solar-terrestrial environment. Sometimes the amplitudes are enormous (e.g. see Fig. 3). Turbulence is present in

- the solar convection zone
- the solar atmosphere
- the solar corona
- the solar wind
- the magnetosheath
- the magnetotail plasma sheet
- the plasmasphere
- the ionosphere

Effects of the turbulence for SEC science may include:

- origin of solar magnetic field
- heating of the corona
- acceleration of the solar wind
- transport of cosmic rays in the heliosphere
- turbulent drag on CMEs
- turbulent drag on magnetosphere
- change in the stability of the magnetotail
- change in dynamics of the magnetotail
- alteration of magnetosheath flow pattern
- enhanced mixing in the plasma sheet
- enabling of small-scale reconnection in tail

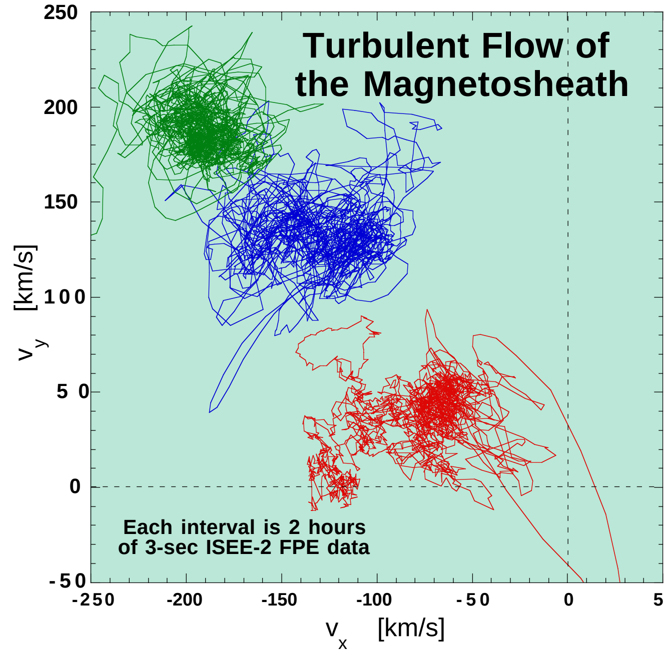

Fig. 3. The robust flow turbulence in the magnetosheath is revealed via velocity hodograms. Hodograms are shown for three locations in the magnetosheath. Each is constructed from a 2-hour-long interval of data.

Our understanding of way turbulence affects the solar-terrestrial environment is in its infancy, relying on analogies with fluids, on educated guesses, and on intuition. Fluid dynamics has utilized data from experiments such as wind tunnels to observe how flows produce turbulence and how turbulence affects flows. These data have allowed fluid dynamists to build empirical models for fluid turbulence which are incorporated into large-scale computational models to simulate such things as flow around airplanes and automobiles. For magnetofluids, no such turbulence models exist. This hampers space physics and hampers astrophysics. SEC has the opportunity to **use the solar system as our wind tunnel to gather the data needed to build turbulence models for magnetofluids**.

— Bill Matthaeus and Joe Borovsky